View metadata, citation and similar papers at core.ac.uk

brought to you by CORE

provided by Elsevier - Publisher Connector

ELSEVIER

Available online at www.sciencedirect.com

ScienceDirect

Procedia Social and Behavioral Sciences 2 (2010) 7633–7635

Procedia
Social and Behavioral Sciences

Sixth International Conference on Sensitivity Analysis of Model Output

# Substitutability vs. Complementarity: Rethinking STI Composite Indicators Building with an Application of Sensitivity Analysis

Giovanni Cerulli[a]*, Andrea Filippetti[b]

[a]Ceris-CNR, Via dei Taurini 19, Rome 00185, Italy
[b]Irpps-CNR, Via Palestro 32, Rome 00185, Italy

**Abstract**

The paper challenges the common view that the arithmetic mean aggregation's rule for building STI indicators is the fairest approach. We argue, on the contrary, that it hides a silent "substitution assumption" among the sub-indicators involved. According to this perspective Casadio and Palazzi (2004) provided a new composite indicator based on a "concave mean". This approach overcomes the "substitution bias" generated by the arithmetic aggregation. As the concave mean is a highly non-linear formula, the paper provides a Sensitivity Analysis (as suggested by Saltelli et al., 2004) to detect sub-indexes importance in this special case. We perform an application to a specific STI indicator comparing results from the concave mean and other aggregation rules.

*Keywords:* STI indicators; Complementarities; Robustness; Sensitivity Analysis

## 1. Main text

Positioning indicators for measuring and comparing countries' Science-Technology-Innovation (in short STI) performance are receiving an increasing attention both on a scientific and political level.

In the last years numerous STI indicators have been proposed. Leading examples are those contained in the Innovation Scoreboard (European Commission, 2008), but other types of new indicators have been built as a consequence of the growing complexity in science, technology and innovation interplay within modern National Systems of Innovation (NSI) (Saisana, 2004; Katz, 2006).

In despite of the different meaning of the various STI indicators proposed in the literature, they often are "composite indicators" obtained by averaging across various sub-indicators using a (weighted or un-weighted) arithmetic mean (Archibugi and Coco, 2005; Hagedoorn and Cloodt, 2003; Grupp and Mogee, 2004). What is

* Corresponding author. Tel.: +39-06-4993-7885; fax: +39-06-4993-7808.
*E-mail address*: g.cerulli@ceris.cnr.it.

1877-0428 © 2010 Published by Elsevier Ltd. Open access under CC BY-NC-ND license.
doi:10.1016/j.sbspro.2010.05.153

sometimes implicitly claimed in order to justify the use of the arithmetic mean is that it is the "simplest" and "fairest" way to gather and synthesize in a single number a multiplicity of elements that all together have to be taken into proper account.

In this paper we want to show that the arithmetic mean hides a "substitution assumption" among the various sub-indicators that is not "neutral" in terms of implied normative recommendations. According to this perspective Casadio and Palazzi (2004) provided a new composite indicator based on a "concave mean" in an application on the field of "sustainable development indices". This approach allows to overcome the limits imposed by the "substitution bias" generated by the arithmetic mean. The concave mean is a highly non-linear aggregation of sub-indexes, thus it becomes interesting to apply a Sensitivity Analysis (SA), as suggested by Saltelli et al. (2004), to detect what sub-indexes explain the greater part of the variance in this special case. Indeed, this aspect loses its attractiveness in a linear context as in the case of the arithmetic mean, while it appears more appropriate in the case of the concave mean.

The substitution assumption states that one country can achieve the same performance by modifying properly the "allocation" of its sub-indicators. In the case of an un-weighted composite indicator built on an arithmetic mean of just two sub-indicators ($I_1$ and $I_2$) we get the following simple formula:

$$I_{AM} = \frac{I_1 + I_2}{2} \tag{1}$$

The "iso-performance curve" associated to (1) is a "line". What a iso-performance line implies is that countries reaching the same ranking position, can have a very different allocation of the two sub-indicators of formula (1). A strong degree of polarization, for example, can appear. Can we accept this "substitution bias" without asking whether it is or not a reasonable assumption in our context? Our answer is "no" and we try to argue on this point. Iso-performance polarized situations rely on the substitution assumption having its roots in a theoretical perspective according to which each factor of socio-economic development can freely offsets the other if opportunely modified. This comes from a "neoclassical" perspective of the functioning of the socio-economic and technological system in which everything can be modified freely and without costs (Malerba, 1999). In contrast with this perspective, evolutionary theories have devoted greater attention to the role played by "complementarities" among the development factors needed to reach specific economic/technological outcomes. The path-dependence theory is one of these examples (David, 1988).

The lesson one can draw from this latter perspective is twofold: (1) polarized situations should not be considered as "equal" since heterogeneous starting conditions matter and could convey divergent future paths and rates of technological progress, (2) more balanced situations should be considered as "better" than polarized ones since they appear to guarantee more "sustainable" development in the future. More balanced situations should be viewed as more reliable and sustainable than polarized ones. To take into account this aspect we need to aggregate the sub-indicators in order to "penalize" polarized situations and "reward" balanced ones. It is quite clear that we need a different from arithmetic mean composite indicator formula, i.e., different iso-performance curves.

Good candidates to overcome this drawback are "convex iso-performance curves". Suppose to have three countries, A, B and C for instance, presenting the same performance value according to the iso-performance line. It could be that country C is in a better position compared to A and B according to the convex iso-performance curve as long as it is closer to the 45° line (in the space generated by the sub-indicators). It means that convex iso-performance curves tend to reward countries with more balanced sub-indices as defined by the 45° line in which $I_1$ and $I_2$ (in the case of two sub-indicators) are equal. This line is defined as the "sustainability path". If country A and B wants to reach country C they have to move their indicators towards a more balance path, i.e., towards the 45° line. Casadio and Palazzi (2004) have shown that a composite formula getting convex iso-performance curves is the so-called "concave mean" having - in its simplest form - the following expression:

$$I_{CM} = \frac{I_1 - e^{-I_1} + I_2 - e^{-I_2}}{2} \tag{2}$$

where the terms $e^{-I_i}$ is called the "sub-indicator $I_i$ penalization". A generalized formula for the concave mean is:

$$I_{CM} = \frac{w_1(I_1 - a_1 e^{-b_1 I_1}) + w_2(I_2 - a_2 e^{-b_2 I_2})}{w_1 + w_1} \tag{3}$$

This formula is, of course, highly non-linear. Therefore the paper aims at applying a Sensitivity Analysis on it using an STI composite indicator derived from the Global Innovation Scoreboard 2008 (GIS 2008) as in the recent application by Archibugi and Filippetti (2009). The GIS 2008 methodology includes 9 indicators of innovation and technological capabilities. They are grouped in three main pillars: Firm Activities and Outputs, Human Resources and Infrastructures and Absorptive Capacity. In the standard methodology for each pillar a Dimension Composite Innovation Index is calculated as a simple average of the indicators. The GIS Index is composed of the three Dimension Composite Innovation Indexes. Our aim is that of comparing results from traditional aggregation rules with those from the concave mean and then looking, by Sensitivity Analysis, at which factors lead to the difference position of countries. A brief comment on results and suggestions for future works will end the paper.

## 2. References


Archibugi D. and Coco A., 2005: "Measuring technological capabilities at the country level: a survey and a menu for choice", *Research Policy*, 34, pp. 175-194.

Archibugi D. and Filippetti A., 2009, "The globalization on technology and the dynamics of the innovative performances", CNR-IRPPS. Paper presented at the workshop on "Ricerca e imprenditorialità nella società della conoscenza", Consiglio Nazionale delle Ricerche, May 19.

Casadio E. and Palazzi P., 2004, "Un indice per lo sviluppo sostenibile", *Moneta e Credito*, 226.

David P.A., 1988, "Path-dependence: putting the past into the future of economics", IMSSS Technical Report No. 533, Stanford University.

European Commission, 2008, "European Innovation Scoreboard 2008: Comparative Analysis of Innovation Performance", Brussels, European Commission.

Grupp H. and Mogee M., 2004, "Indicators for national science and technology policy: how robust are composite indicators?", *Research Policy*, 33, pp. 1373- 1384.

Hagedoorn J. and Cloodt M., 2003, "Measuring innovative performance: is there an advantage in using multiple indicators?", *Research Policy*, 32, pp. 1365-1379.

Katz J.,2006, "Indicators for complex innovation systems", *Research Policy*, 35, pp. 893-909.

Malerba F., 1999, "Sectoral systems of innovation and production", DRUID Conference on: National Innovation Systems, Industrial Dynamics and Innovation Policy, Rebild, June 9-12.

Saisana M., 2004, "Composite indicators: a review", Second workshop on composite indicators of country performance, OECD, Paris.

Saltelli A. et al., 2004, "Sensitivity analysis in practice. A guide to assessing scientific models", John Wiley & Sons.